

Surface Roughness in Abrasive Waterjet Cutting of Copper – An Experimental Study

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Abstract— Abrasive waterjet cutting is one of the non-traditional cutting processes capable of cutting wide range of hard-to-cut materials. This paper assesses the influence of process parameters on surface roughness which is an important cutting performance measure in abrasive waterjet cutting of copper. Experiments were conducted in varying water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance for cutting copper using abrasive waterjet cutting process. The effects of these parameters on surface roughness have been studied.

Keywords-abrasive waterjet; garnet; copper; water pressure, mass flow rate; traverse speed; standoff distance; surface roughness.

I. INTRODUCTION

Abrasive waterjet cutting [AWJC] has various distinct advantages over the other non-traditional cutting technologies, such as no thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces and has been proven to be an effective technology for processing various engineering materials [1]. It is superior to many other cutting techniques in processing variety of materials and has found extensive applications in industry [2]. In this method, a stream of small abrasive particles is introduced in the waterjet in such a manner that waterjet's momentum is partly transferred to the abrasive particles. The main role of water is primarily to accelerate large quantities of abrasive particles to a high velocity and to produce a high coherent jet. This jet is then directed towards working area to perform cutting [3]. It is also a cost effective and environmentally friendly technique that can be adopted for processing number of engineering materials particularly difficult-to-cut materials such as ceramics [4, 5]. However, AWJC has some limitations and drawbacks. It may generate loud noise and a messy working environment. It may also create tapered edges on the kerf, especially when cutting at high traverse rates [6, 7].

As in the case of every machining process, the quality of AWJC process is significantly affected by the process tuning parameters [8, 9]. There are numerous associated parameters in this technique, among which water pressure, abrasive flow rate, jet traverse rate, standoff distance and diameter of focusing nozzle are of great importance but precisely

controllable [10, 11]. The main process quality measures include attainable depth of cut, kerf width and surface finish. Number of techniques for improving kerf quality and surface finish has been proposed [10-13].

In this paper surface roughness is considered as the performance measure as in many industrial application it is the main constraint on the process applicability. In order to effectively control and optimize the AWJC process, predictive models for depth of cut have been already developed for ceramics, aluminium etc. [14-16]. More work is required to fully understand the influence of the important process parameters on surface roughness of copper. This paper assesses the influence of abrasive waterjet cutting process parameters on surface roughness of copper.

II. EXPERIMENTAL WORK

A. Material

Copper is a reddish brown nonferrous metal which has been used for thousands of years by many cultures. It is a ductile metal with very high thermal and electrical conductivity. Modern life has a number of applications for copper, ranging from coins to pigments, and demand for copper remains high, especially in industrialized nations. Copper bars of thickness 90 mm were used as the specimens. It has the following mechanical properties: Density = 8000 kg/m³; Modulus of elasticity = 117,000 MPa; Yield Strength = 100 MPa; Thermal conductivity = 398 W/m-K.

B. Equipment

The equipment used for machining the samples was Water Jet Sweden cutter which was equipped with KMT ultrahigh pressure pump with the designed pressure of 4000 bar. The machine is equipped with a gravity feed type of abrasive hopper, an abrasive feeder system, a pneumatically controlled valve and a work piece table with dimension of 3000 mm x 1500 mm. Sapphire orifice was used to transform the high-pressure water into a collimated jet, with a carbide nozzle to form an abrasive waterjet. The abrasive waterjet cutting head is shown in figure 1. Throughout the experiments, the nozzle was frequently checked and replaced with a new one whenever the nozzle was worn out significantly. The abrasives

were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The debris of material and the slurry were collected into a catcher tank.

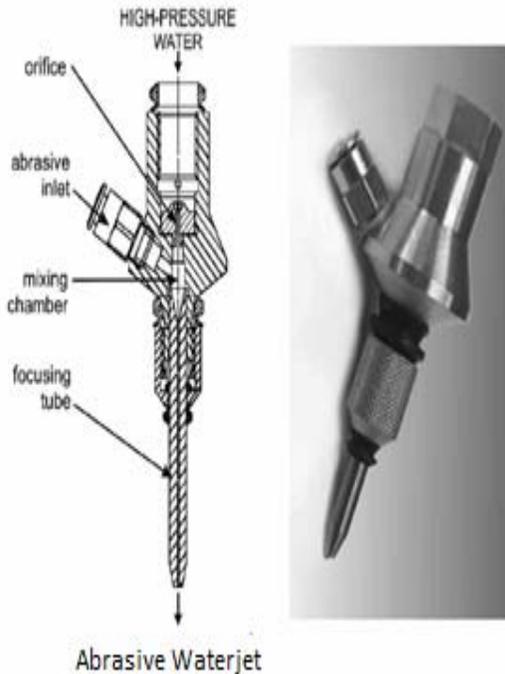


Figure 1. Abrasive waterjet cutting head

C. Design of Experiments (DOE)

Design of experiments (DOE) techniques enable designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. To achieve a thorough cut it was required that the combinations of the process variables give the jet enough energy to penetrate through the specimens. In the present study four process parameters were selected as control factors. The parameters and levels were selected based on the literature review of some studies that had been documented on AWJC on graphite/epoxy laminates [17], metallic coated sheet steels [18] and fiber-reinforced plastics [19]. Taguchi's experimental design was used to construct the design of experiments (DOE). Four process parameters, i.e. water pressure, nozzle traverse speed, mass flow rate of abrasive particles and standoff distance each varied at three levels as shown in table 1, an $L_{81} (3^4)$ orthogonal arrays table with 81 rows corresponding to the number of experiments was selected for the experimentation. Table 1 shows the levels of parameters used in experiment.

Table 1 Levels of parameters used in experiment

Parameters	Unit	Level 1	Level 2	Level 3
Water pressure	MPa	270	335	400
Traverse speed	mm/s	0.5	10.25	20
Mass flow rate	g/s	8	11.5	15
Standoff distance	mm	1.8	3.4	5

D. Constant Parameters

The parameters that were kept constant during tests included the jet impact angle at neutral nozzle position (90°), orifice diameter (0.35 mm), nozzle length (76.2 mm), nozzle diameter (1.05 mm), abrasive material (80 mesh garnet particles with the density of 4100 kg/m^3) and average diameter of abrasive particles (0.18 mm). Garnet consists of chemically 36% FeO, 33% SiO₂, 20% Al₂O₃, 4% MgO, 3% TiO₂, 2% CaO and 2% MnO₂.

E. Data Collection

For each experiment, the machining parameters were set to the pre-defined levels according to the orthogonal array. All machining procedures were done using a single pass cutting. The abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The abrasive flow rates were calibrated by measuring the time spent for a certain weight of abrasives to be completely consumed in the hopper. The supply pressure was manually controlled using a pressure gauge. The standoff distance is controlled through the controller in the operator control stand. The traverse speed and supply of abrasives were automatically controlled by the abrasive waterjet system programmed by NC code. The surface finish parameter employed to indicate the surface quality in this experiment was the arithmetic mean roughness (R_a). Workpiece surface roughness R_a was measured by a surface roughness equipment model "SURFPAK SV-514". Surface roughness was measured at the centre of the cut for each specimen. Each measurement of R_a was taken three times and their arithmetic mean was calculated as to minimize the error.

III. RESULTS AND DISCUSSION

Surface roughness is one of the most important criteria, which help us determine how rough a workpiece material is machined. In all the investigations it was found that the machined surface is smoother near the jet entrance and gradually becomes rougher towards the jet exit. This is due to the fact that as the particles moves down they loose their kinetic energy and their cutting ability deteriorates. By analyzing the experimental data of all the selected materials, it

has been found that the optimum selection of the four basic parameters, i.e., water pressure, abrasive mass flow rate, nozzle traverse speed and nozzle standoff distance are very important on controlling the process outputs such as surface roughness. The effect of each of these parameters is studied while keeping the other parameters considered in this study as constant. The following discussion uses the experimental data at the centre of the cut for each specimen and the surface roughness is assessed based on the centre-line average R_a .

A. Effect of water pressure on surface roughness

In this experimental study, mass flow rate, traverse speed and standoff distance were kept 15 g/s, 0.5 mm/s and 1.85 mm respectively. The surface roughness gradually decreases when the water pressure increases from 270 MPa to 395 MPa. The influence of water pressure on the surface roughness is shown in fig.2. Jet pressure plays an important role in surface finish. As the jet pressure increases, surface becomes smoother. With increase in jet pressure, brittle abrasives break down into smaller ones. As a result of reduction of size of the abrasives the surface becomes smoother. Again, due to increase in jet pressure, the kinetic energy of the particles increases which results in smoother machined surface.

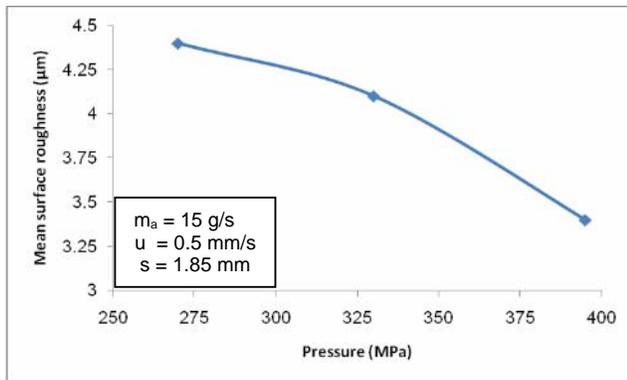


Figure 2. Effect of pressure on surface roughness

B. Effect of abrasive mass flow rate on surface roughness

During this cutting process the water pressure was 395 MPa, traverse speed was 0.5 mm/s and standoff distance was 1.85 mm. As the mass flow rate is increased from 8 g/s to 15 g/s, the surface roughness is decreased. It needs a large number of impacts per unit area under a certain pressure to overcome the bonding strength of any material. With the increase in abrasive flow rate, surface roughness decreases. This is because of more number of impacts and cutting edges available per unit area with a higher abrasive flow rate. Abrasive flow rate determines the number of impacting abrasive particles as well as total kinetic energy available. Therefore, higher abrasive flow rate, higher should be the

cutting ability of the jet. But for higher abrasive flow rate, abrasives collide among themselves and loose their kinetic energy. It is evident that the surface is smoother near the jet entrance and gradually the surface roughness increases towards the jet exit. The effect of abrasive mass flow rate on surface roughness is shown in fig. 3.

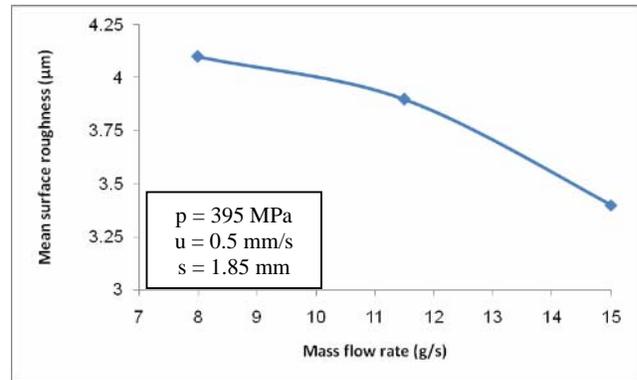


Figure 3. Effect of abrasive mass flow rate on surface roughness

C. Effect of traverse speed on surface roughness

The relationship between the traverse speed and the surface roughness is shown in fig. 4. The other three process parameters namely; mass flow rate, water pressure and standoff distance were kept constant as 15 g/s, 395 MPa and 1.85 mm respectively. The general trend of the curve shows that increase in traverse speed from 4.2 mm/s to 20 mm/s results in increase in surface roughness. For decreasing of the machining costs every user try to choose the feed rate of the cutting head as high as possible, but increasing the traverse speed always causes increasing of inaccuracy and surface roughness. But with increase in work feed rate the surface roughness increased. This is due to the fact that as the work moves faster, less number of particles are available that pass through a unit area. Therefore, less number of impacts and cutting edges are available per unit area, which results a rougher surface.

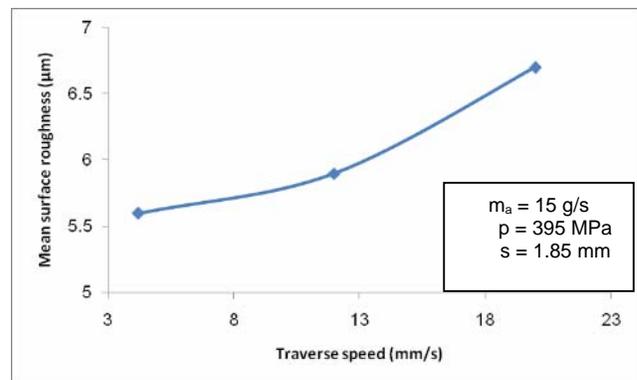


Figure 4. Effect of traverse speed on surface roughness

D. Effect of standoff distance on surface roughness

Surface roughness increase with increase in standoff distance. Figure 5 shows the relationship between standoff distance ranging from 1.85 mm to 5 mm and surface roughness. During this cutting process mass flow rate, water pressure and traverse speed were 15 g/s, 395 MPa and 0.5 mm/s respectively. There is an increase in surface roughness is seen when the standoff distance is increased. Generally, higher standoff distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment. Therefore, increase in the standoff distance results an increased jet diameter as cutting is initiated and in turn, reduces the kinetic energy of the jet at impingement. So surface roughness increase with increase in standoff distance. It is desirable to have a lower standoff distance which may produce a smoother surface due to increased kinetic energy. The machined surface is smoother near the top of the surface and becomes rougher at greater depths from the top surface.

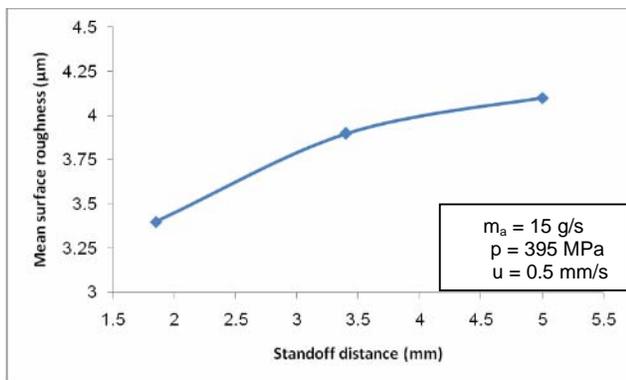


Figure 5. Effect of standoff distance on surface roughness

IV. CONCLUSION

Experimental investigations have been carried for the surface roughness in abrasive waterjet cutting of copper. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and standoff distance on surface roughness have been investigated. As a result of this study, it is observed that these operational parameters have direct effect on surface roughness. It has been found that water pressure has the most effect on the surface roughness. An increase in water pressure is associated with a decrease in surface roughness. These findings indicate that the use of high water pressure is preferred to obtain good surface finish. Surface roughness constantly decreases as mass flow rate increases. It is recommended to use more mass flow rate to decrease surface roughness. Among the process parameters

considered in this study water pressure and abrasive mass flow rate have the similar effect on surface roughness. As nozzle traverse speed increase, surface roughness increases. This means that low traverse speed should be used to have more surface smoothness but is at the cost of sacrificing productivity. This study has resulted surface smoothness increase as standoff distance decreases. Therefore to achieve an overall cutting performance, low standoff distance should be selected.

NOMENCLATURE

- p water pressure (MPa)
- m_a mass flow rate of abrasive particles (g/s)
- u traverse speed of nozzle (mm/s)
- s standoff distance (mm)

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